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Senior Design Project Report

“Design of Experiments of Shell and Tube Heat Exchanger with Nanofluid Medium”

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Abstract

Heat transfer is one of the most important processes inside the industry so increasing heat exchanger efficiency has a great use and major beneficial effect to the heat transfer. Nanoparticles typically have some different properties that eventually improve the performance of heat exchange between two fluids. Nanoparticles are particles with a diameter of 1 to 100 (nm) in size with special related properties.

The project objective is to design an experimental system of shell and tube heat exchanger using nanoparticles in the shell side. Comparison with pure fluid, the experiment is to be characterized of two types of powder nanoparticles, which are aluminum oxide nanoparticle and pure copper nanoparticle, both types of nanoparticles are mixed with water separately as a heat transfer medium through the shell and tube heat exchanger. We examined the discrepancy in performance and efficiency of the heat exchanger when nanoparticle is utilized instead of the normal process fluids.

The result is shown improvement in efficiency when using nanoparticles as a heat transfer medium since nanoparticles possess more advantageous to the conventional heat transfer resulting in transferring heat more efficiently.

Acknowledgments

We would like to thank our advisor Dr. Esam Jassim and Co-Advisor Dr. Faizan Ahmad for the great helping and guiding our group on the project course. With the help and experience from them, we greatly succeed to make the experiment of Design of Experiments of Shell and Tube Heat Exchanger with Nanofluid Medium, and we also succeed to develop our knowledge on the heat transfer side and the use of Nanofluids with its effect with relation to the heat transfer. It was a great constructive suggestion that it supported all of our group members to work and deliver the information and lesson learns to the entire group, which assets all members to contribute and understand the concepts of the project. It was a challenging and successful academic semester with the essential completion of the project. Also, we gladly appreciate all the extreme help that we got from other faculty from Prince Mohammed Bin Fahd University and we appreciate their valuable inputs and knowledge that we got from them.

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List of Acronyms (Symbols)

NF	Nanofluids, a fluid containing nanometer-sized particles
HE	Heat Exchanger, a device used to transfer heat between two or more fluids
HT	Heat Transfer
OHTC	Overall Heat Transfer Coefficient
AV	Apparent Viscosity
PV	Plastic Viscosity
YP	Yield point

Chapter 1: Introduction

1. Introduction

Heat exchangers are widely used in many engineering applications, for example, in automotive industries, chemical industry, environment engineering, waste heat recovery, air conditioning, refrigeration, power production, and food industry. Hence, increasing heat exchanger efficiency has a great advantages and major beneficial to the community. One way to enhance the overall heat transfer coefficient in heat exchangers is by mixing additives to the liquids. Thermal conductivity of the mixed fluid plays an important role in such enhancement since it improves the energy transfer between the working fluid and the heated surface.

Applications of nanotechnology in classical thermal designs present nanofluid (NF) as a new class of fluids to increase the rate of heat transfer. Since conventional HT fluids including water, oil, and Ethylene Glycol (EG) show relatively poor characteristics in transferring energy, an innovative method to improve the thermal conductivity of certain fluid can be obtained by suspending Nano-sized particles with high thermal conductivity in the base fluid with low thermal conductivity. In recent years, extensive research has proven that nanofluids are superior as a heat transfer agent over conventional fluid.

Nanofluids are formed by dispersing solid particles, fibers, or tubes of 1 to 100 nm size in conventional HT fluids. NFs have remarkable characteristics associated such as high heat

transfer rate, low fluctuation ability through passages, and thermal homogeneity. In this view, NFs are nowadays extensively demanded in electronics and automotive industries. Consequently, further study on HT characteristics of NF suspensions becomes essential.

1.1 Problem Description

In this project an experimental system of shell and tube heat exchanger is designed using nanoparticles in the shell side. Results are compared with pure fluid. The experiment is to be characterized of two types of powder nanoparticles, which are aluminum oxide nanoparticle and pure copper nanoparticle, both types are to be mixed with water separately as a heat transfer medium through the shell side of the shell-and-tube heat exchanger. Performance and efficiency of the heat exchanger are examined when nanoparticle is utilized instead of the normal process fluids.

1.2 Project scope and objectives

This study is an attempt to address the performance and efficiency of shell and tube heat exchanger using Nano-particles. The study has the following objectives:

- i. Design of an experimental setup to perform study.
- ii. Perform the experiment to investigate the impact of adding Nano fluid to the performance of the heat exchangers.
- iii. Optimize the results by comparing the experimental outcome with the theoretical result.
- iv. Provide recommendations to enhance the performance of shell and tube heat exchanger.

Chapter 2: Literature Review

In recent years, extensive research has proven that nanofluids are superior as a heat transfer agent over conventional fluid. Numerous aspects are still on going and need to be addressed in this field. In this section, a literature review is presented to facilitate the discussion on the experimental work the conducted in this study.

Although Masuda et al. (1993) presented the structure of liquid suspended of nano-sized particles, it was Choi (1995) who proposed the name of nanofluid for the first time. Ever since Choi [1] published the first findings in NFs studies, there have been several other works has been done to the improvement of HT up to 20% by using densely distribution of nanoparticles in NFs. Efforts were carried out for better comprehension of changes in heat transfer coefficient in heat exchangers. Heat transfer coefficient of NFs with very low particle volume % is much higher as referred to the base fluid. On the other hand, low changes in friction coefficient and fluid viscosity in NFs have been reported [2-3].

Xuan and Roetzel [4] noticed an increase in energy transfer rate in their investigation on random motion of nanoparticles in NF. An experimental study on the convective HT and flow characteristics of water-Cu NF through a straight pipe with constant thermal flow under laminar and turbulent regimes has been reported. Nanoparticles of Cu with less than 100 nm diameter were employed. The results show that Nano-suspended particles substantially improved the performance of conventional base fluid HT. The volume fraction of base fluid in NF fits well with that of water.

Pak and Cho (1998) [5] found in their experiment, the turbulent forced convection heat transfer of Al_2O_3 /water is higher than TiO_2 /water nanofluids inside a circular tube.

Li and Xuan (2002) [6] concluded that in laminar and turbulent flow regime in forced convection, the heat transfer coefficient of Cu/water nanofluids flowing inside a uniformly heated tube remarkably increased compared to that of pure water.

Lotfi et al. [7] have compared the single-phase with the Mixture and Eulerian two-phase models for the forced convection flow of Al_2O_3 /Water nanofluid with temperature independent properties. Also, they have compared the Nusselt number predictions for a 1% value concentration of nanoparticles with several correlations and one set of experimental values. They have also studied the effect of volume concentration on the wall temperature. Their results showed that the Mixture model is more precise than the other two models.

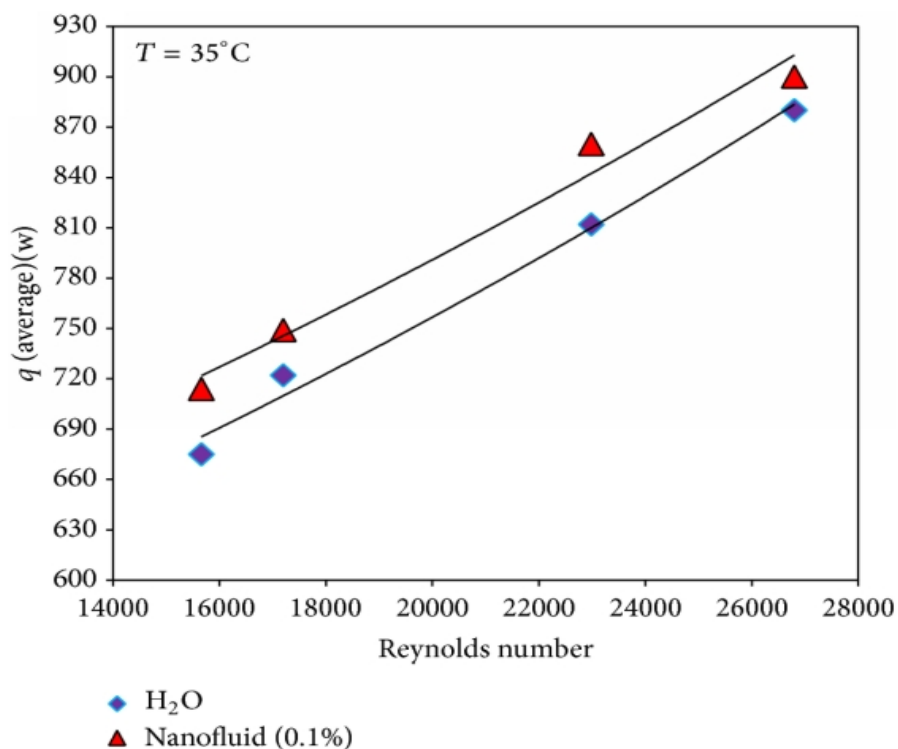
2.1 Effect of Nanoparticles on Thermal Efficiency of Double Tube Heat Exchanger

Reza Aghayari et. al. [8] did the experiments to find an Overall Heat Transfer Coefficient of Nano Fluids (OHTCNF) in heat exchangers and other relevant effective parameters. An improvement in Heat Transfer (HT) and OHTCNF containing Nano-aluminum oxide with ca.

20 nm particle size and particular volume fraction in the range of 0.001-0.002 was reported. The effects of temperature and concentration of nanoparticles on HT variation as well as Overall Heat Transfer Coefficient (OHTC) in a countercurrent double tube heat exchanger with turbulent flow have been studied. The experimental results fig: 1 shows a remarkable 8%–10% rise in the mean HT and the OHTC.

In general, there are three mechanisms to improve heat transfer by introducing nanoparticles into the base fluid.

- Nano-particles benefit higher heat transfer rate; therefore, as nanoparticle concentration in the base fluid increases the heat transfer rate increases accordingly.
- The collisions occur between nanoparticles and the base fluid molecules on the one hand and the impacts of the particles to the heat exchanger wall on the other hand result in an energy increase.
- The friction between the wall and fluid increases if NFs are dealt with and, therefore, heat transfer improves.



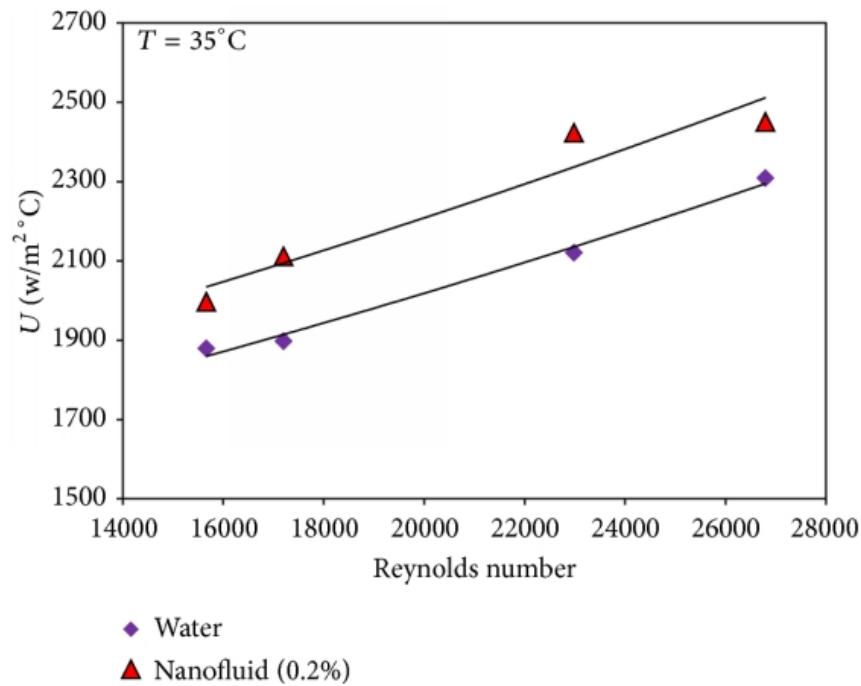


Figure 2.1: Variation of mean heat flow rate and overall heat transfer coefficient with Reynolds number for NF 0.1% and water at $T = 35^\circ\text{C}$.

2.2 The effect of nanoparticles on the heat transfer properties of drilling fluids

Hassani et al. has been found that the velocity and temperature have an important effect on the thermal property of mud. The thermal performance factor for all the cases is greater than base mud (5–22% for 0.01–2 wt% nano-material) and convection results showed that the maximum thermal performance was found for the hybrid of CNT-silica nano-particle in higher Reynolds number. The heat transfer enhancement in 4200 Reynolds number, is 31%, 24% and 74% in 200, 400 and 588 W (heat fluxes), respectively. Furthermore, the rheological properties such as apparent viscosity (AV), plastic viscosity (PV) and yield point (YP) are improved by adding nano-particles to the drilling mud. Following conclusion were drawn in this study:

- Dispersing nano-particles in the base fluid reveal increases of thermal performance with an increase in the nano-particle concentration.
- The specific heat capacities of nano-muds are negligible changes compared to the base mud and it is increased with increasing of nano-particles concentration. The

enhancement in thermal performance and specific heat is due to the high surface area of the nano-particles per volume that provides high surface energy.

- The thermal conductivity at the temperature of 40 °C, is enhanced by a maximum of 22% and 16.9% at a volume fraction of 2% ZnO and SiO₂, respectively.

2.3 Conclusion from Literature Review

Based on the literature review done it can be concluded that,

- Introducing nanoparticles to the fluid will increase heat transfer coefficient of the system in both laminar and turbulent regimes.
- Surface properties, particle shape, and concentration of nanoparticles play important role to improve NF heat transfer properties.
- The elevated heat transfer coefficient may attribute to the higher concentrations of nanoparticles adjacent to the wall caused by particle migration phenomenon.
- The momentum of suspended particles increases as the NF mass flow rate increases. Accordingly, the collision of nanoparticles to the wall becomes even more intense. Friction to the wall as a function of wall surface properties and NF characteristics may need to be studied.
- Further research work needs to be done to better understand the NF heat transfer properties and develop more relations.

Chapter 3: Specification and System Design

3.1 System Block Diagram

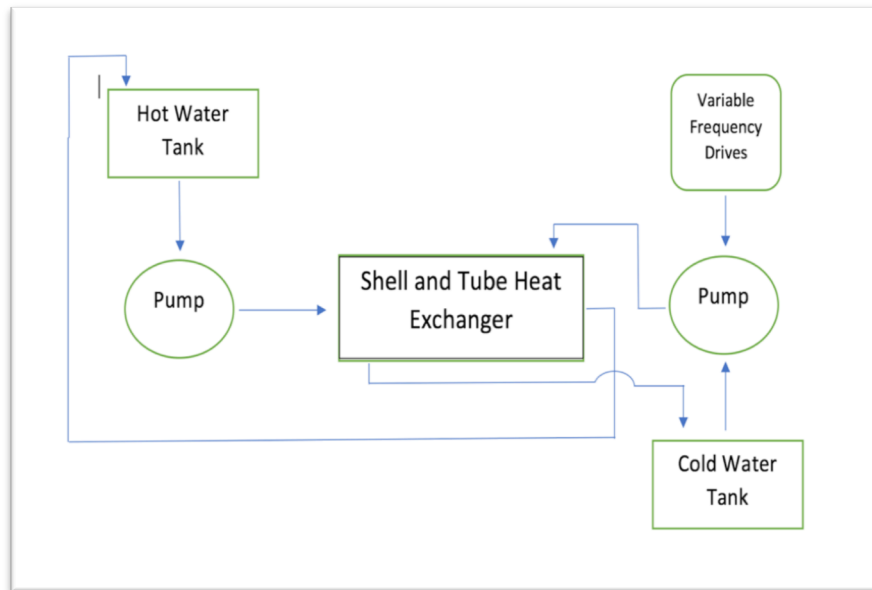


Figure 3.1: Block diagram

3.1.1 Specifications and Standards

System of shell and tube heat exchanger designed with two cycles separately which are the hot water cycle and cold-water cycle, each system consists of a tank volume for fluid accumulate and pump with variable frequency drive (VFD) to control fluid flow rate. Using three types of mediums which are water, pure copper nanoparticles powder and aluminum oxide nanoparticles powder. Nanoparticles that have been used follows standard available sizes of nanoparticle with unit of Nano meter on the international market, joining fittings follows standard sizes available on local markets.

3.1.2 System design alternatives

Joining fittings have been used ordered from the local markets and available amount ordered for alternating parts for any part failure or design change, also the nanoparticle powder ordered with enough amount for various tests experiments and test failure considerations.

3.1.3 Target specifications and Engineering standards

System specification design target follows slandered engineering experimental setup and perform studies and calculations. Standard numbers for nanoparticles are CAS 7440-50-8 and

CAS 1344-28-1 for the pure copper and aluminum oxide respectively, the standard number for joining fittings and piping are ASTM D2564 and ASTM D1785 respectively.

3.2 Design Constraints and Design Methodology

Several designs constrain have been implicated in the project they are as follows:

3.2.1 Design Methodology

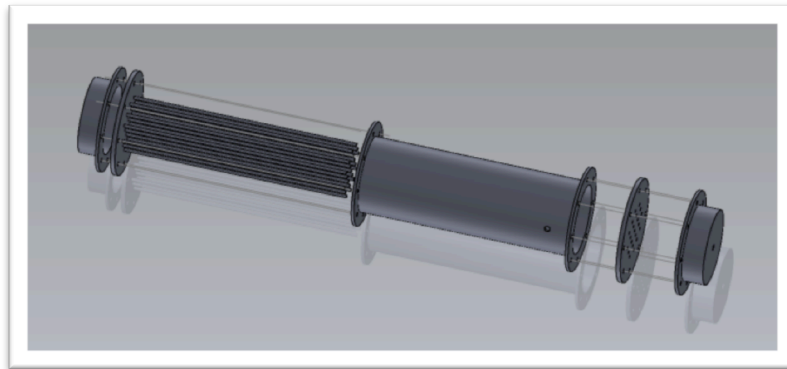


Figure 3.2.1a: Design assembly of Heat Exchanger

This study is an attempt to address the performance and efficiency of shell and tube heat exchanger using Nano-particles. The study has the following objectives:

- A. Design of an experimental setup to perform study.
- B. Perform the experiment to investigate the impact of adding Nano fluid to the performance of the heat exchangers.
- C. Optimize the results by comparing the experimental outcome with the theoretical result.
- D. Provide recommendations to enhance the performance of shell and tube heat exchanger.

3.2.1.1 Shell and tube heat exchanger

The shell and tube heat exchanger consist of two cycles which are cold and hot water cycles. The exchanger has two inlets and two outlets for the hot and the cold flow. There are two ways to do the experiment in the heat exchanger, which are the parallel and the counter flow.

However, using the counter flow will give a better efficiency than the parallel one. The exchanger has seven thermocouples distributed between the hot and cold circuits, these thermocouples located on the inlets, outlets and immediate points of the shell and tube heat exchanger. Also, the experiment has two flow rate sensors (SC-1 and SC-2) rate of hot and cold flow respectively, which allow to measure the flow rates for both hot and cold-water flow.

3.2.1.2 Hot water cycle

Hot water flows through a closed circuit, exits the tank with flow rate measured by the flow rate sensor (SC-16). Then, the hot water flowing directly to the inlet of the tube side of the heat exchanger. The temperature of the hot water inlet measured by the thermocouple (ST-1), the flows inside the tubes. The outlet of the hot water is measured by the thermocouple (ST-2). When the hot water leaves heat exchanger returns back to the hot water tank.

3.2.1.3 Cold Water cycle

The cold-water cycle flows into a closed cycle starts on the cold-water tank and flow to the shell side of the heat exchanger with flow rate measured by the flow rate sensor (SC-2). on the shell side, the inlet temperature measured by the thermocouple (ST-7) and exits with thermocouple measurement (ST-3). Three immediate thermocouples to measure the segment part temperature difference during the flow of the cold water, these thermocouples are (ST-4, ST-5 and ST-6).

3.2.2 Geometrical Constraints

Limited flow rate and the size limitation of the piping and joining sizes results to make little amount of the nanoparticles sticks on the bottom of the shell surface where the cold flow access from the pipes to the shell where the volume increasing results to reduce the velocity as a constant mass flow rate on the system.

3.2.3 Safety

Safety is an important factor to be considered during work and experiment implementation.

3.2.3.1 Hot water tank

The water temperatures for the hot tank reach around 50 °C. So, to avoid touching the hot tank we put stamp mark on the hot surface of the hot water tank.



Figure 3.2.3.1a: Hot water tank

3.2.3.2 Nanoparticles

Nanoparticles have the ability to harm the human body by interacting through various mechanisms, so it is required to use personnel protective equipment: gloves, masks and safety glasses.

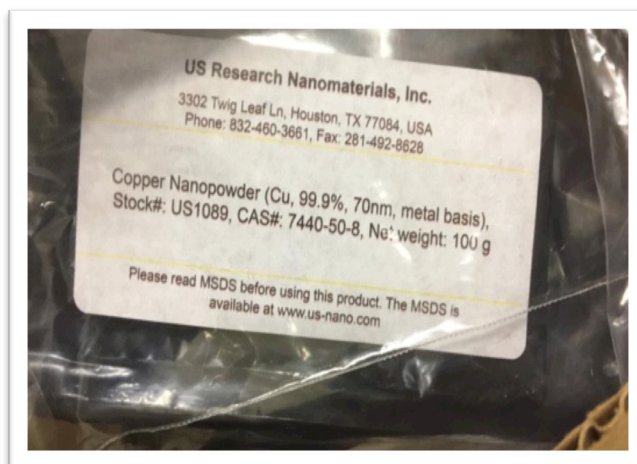


Figure 3.2.3.2a: Copper powder nanoparticles

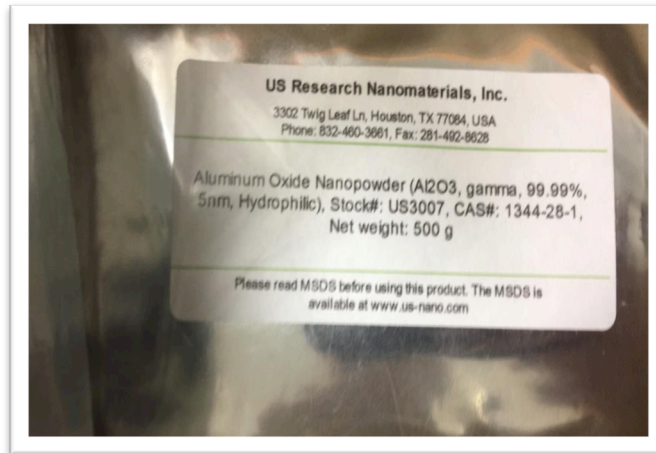


Figure 3.2.3.2b: Aluminum oxide powder nanoparticles

3.2.3.3 Variable Frequency Drives

The use of variable frequency drives (VFD) is made to control of Flow and variable speed of the pump. the maximum pressure for the heat exchanger gauges is 0.7 bar, so we used the VFD to control the pump flow pressure to not damage the tube of the system.



Figure 3.2.3.3a: Variable frequency drives

3.2.4 Pump Selection

Pump selections are one of the constraints that we faced during selecting materials required. Therefore, we looked for pump having a variable flow rate controller, this pump was not available in the local market, for that reason we used a separate device (VFD).

3.2.5 Flow Rate Sensor

The flow rate sensor of the Edibon heat exchanger device will not read the flow rate of the nanoparticle so we used the Digiflow 6710M Digital flow meter device.

3.2.6 Economic and Part Availability

The Aluminum oxide and pure copper nanoparticles are not available on the local market, which effects the economical side with additional factor of payments, and shipping on the international markets, we found these nanoparticles on the US market from US Research Nanoparticles, Inc.

3.3 Engineering Design Standards

3.3.1 Heat Exchanger Assembly Standard

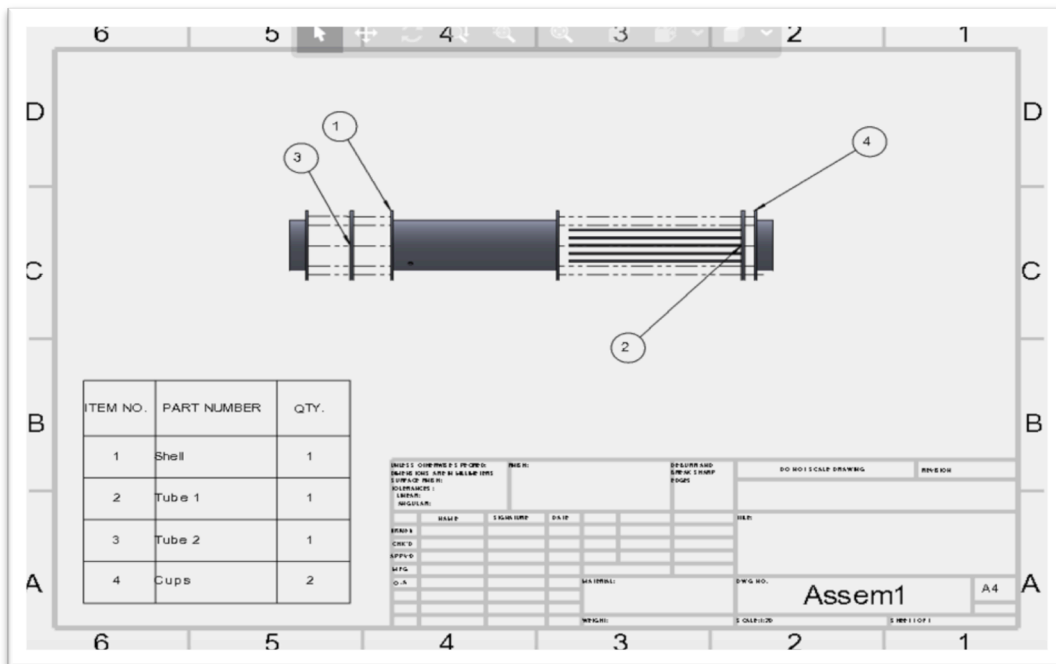


Figure 3.3.1a: Heat exchanger assembly standard

3.3.2 Parts and Shipments Standard

Table 3.3.2a: Material Engineering standard

Material	Engineering Standard
Pure Copper	CAS 7440-50-8
Aluminum Oxide	CAS 1344-28-1
Joining Fittings	ASTM D4673
Nylon Hose	ASTM F2785

3.4 Theory and Theoretical Calculations

Counter flow is preferred, as the difference in temperature between the hot and cold fluids is relatively constant along the full length of the heat exchanger. This is a benefit because extreme differences in temperature are eliminated that can thermally stress the heat exchanger material

3.4.1 Temperature Difference

Temperature difference is the change in temperature between the inlet and outlet temperature for either the cold flow or the hot flow, following are the equations of temperature difference:

$$\Delta T_h = (ST-1) - (ST-2)$$

Equation (3-1)

$$\Delta T_c = (ST-3) - (ST-7)$$

Equation (3-2)

Where:

ΔT_h : hot fluid temperature difference.

ΔT_c : cold fluid temperature difference.

ST-1: hot fluid inlet temperature.

ST-2: hot fluid exit temperature.

ST-3: cold fluid exit temperature.

ST-7: cold fluid inlet temperature.

3.4.2 Rate of Heat Transfer

The rate of heat transfer is the amount of heat transferred between the hot and cold flows in addition to the heat losses, as the following equations:

$$Q_h = m_h C_p (\Delta T_h)$$

Equation (3-3)

$$Q_c = m_c C_p (\Delta T_c)$$

Equation (3-4)

$$Q_l = Q_h - Q_c$$

Equation (3-5)

Where: -

Q_h : Heat transfer rate for hot fluid

Q_c : Cold transfer rate for hot fluid

Q_l : Heat losses

m : Mass flow rate

C_p : Specific heat transfer at constant pressure

3.4.3 Effectiveness

Effectiveness is the percent of a product to produce the desired result, formulated as the following equation:

$$\epsilon = Q_{\text{actual}} / Q_{\text{max}} \quad \text{Equation (3-6)}$$

Where:

ϵ : Effectiveness

Q_{actual} : the minimum heat fluid (cold or hot)

Q_{max} : $m_{\text{min}} C_p (\Delta T_{\text{in}})$

3.4.4 Reynold Number

Reynold number is an analytical method to determine the type of flow either laminar flow or turbulent. As the following equation:

$$Re = 4m / \mu\pi D \quad \text{Equation (3-7)}$$

Where:

Re: Reynold number.

μ : dynamic viscosity.

D: diameter.

3.5 Product Subsystems and selection of Components

We selected copper and aluminum oxide nanoparticle due to the higher thermal conductivity rather than normal sized particles, which helps to increase the rate of heat transfer and the efficiency of the shell and tube heat exchanger. The selection of the nanoparticle based on the following:

- Pure copper Nanopowder (Cu, 70 nm, 99.9% purity, metal basis).
- Aluminum Oxide Nanopowder (Al₂O₃, 5 nm, 99.9% purity, Hydrophilic).

3.6 Manufacturing and assembly (Implementation)

All the parts that we bought are standard and can be used under a specific pressure and temperature. The design temperature is the temperature to be used in the design of the heat exchanger. Same as with the design pressure, this value is defined by the thermal design. First of all, put the shell and tube above a smooth surface and make sure the shell and tube are empty. Then connect the hot cycle and the cold cycle. Make sure the valves are organized in which the flow type is counter flow.

3.7 Project prototype

The below pictures show our main parts of our project prototype (*Design of Experiments of Shell and Tube Heat Exchanger with Nanofluid Medium*) :

- 1) Heat exchanger (Edibon system including TIUS base service unit, Control interface box and TICT shell and tube heat exchanger).
- 2) Variable frequency drive (VFD).
- 3) Pmp.
- 4) Two Tanks.
- 5) Connections (Hoses, valves, sensors).
- 6) Nanoparticles Mixer.



Figure 3.7.1: The design setup.

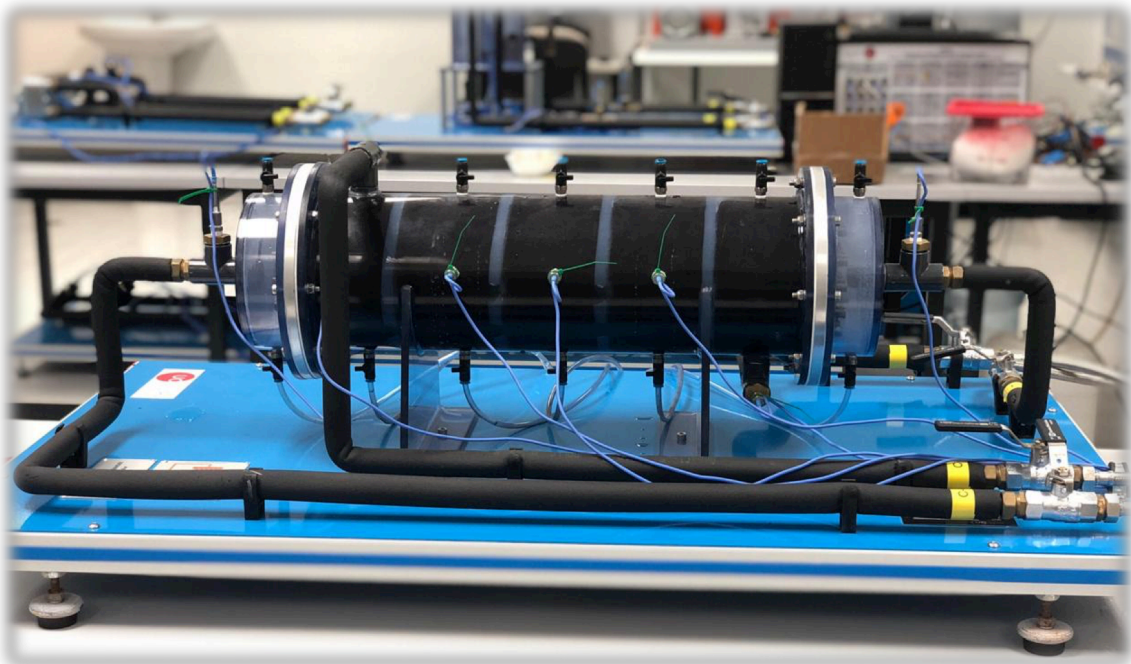


Figure 3.7.2: Heat exchanger.



Figure 3.7.3: Variable frequency drive (VFD).



Figure 3.7.4: Pump.



Figure 3.7.5: Nanoparticles Mixer.

Chapter 4: System Testing and Analysis

4.1 Results

The data analysis that found on the experiments and equation calculation as following:

Table 4.1: Water result.

		Water					
		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30	40	50	50		
T _∞	Room Temperature °C	21.7			21.7		
SC-1 (ṁ _h)	Hot fluid mass flow rate kg/s	1.7/60			1.9/60		
SC-2 (ṁ _c)	Cold fluid mass flow rate kg/s	1.7/60			1.0/60	1.5/60	1.9/60
ST-1	Hot fluid inlet °C	26.4	32.8	40.2	42.5	43.2	43.6
ST-2	Hot fluid exit °C	23.8	26.7	30.5	31.4	32.6	33.2
ST-3	Cold fluid exit °C	23.7	27.9	33.5	36.1	37.9	38.3
ST-7	Cold fluid inlet °C	22.9	25	28.9	30.8	31.7	33.9
ΔT _h	ΔT hot °C	2.6	6.1	9.7	11.1	10.6	10.4
ΔT _c	ΔT cold °C	0.8	2.9	4.6	5.3	6.2	4.4
Q _h	Heat transfer rate for hot fluid W	0.31	0.72	1.15	0.78	1.11	1.38
Q _c	Heat transfer rate for cold fluid W	0.09	0.34	0.55	0.37	0.65	0.58
Q _l	Loss of heat transfer W	0.21	0.38	0.61	0.41	0.46	0.80
E	Effectiveness	23%	37%	41%	45%	54%	45%
Re	Reynold #	2249.09	2249.09	2249.09	1322.99	1984.49	2513.69

Table 4.1.1: Pure copper with mass of fraction (0.25%)

		Pure copper with mass of fraction (0.25%)					
		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30	40	50	50		
T _∞	Room Temperature °C	21.7			21.7		
SC-1 (ṁ _h)	Hot fluid mass flow rate kg/s	1.7/60			1.9/60		
SC-2 (ṁ _c)	Cold fluid mass flow rate kg/s	1.7/60			1.0/60	1.5/60	1.9/60
ST-1	Hot fluid inlet °C	28.7	34.4	41.6	42.5	43.1	43.4
ST-2	Hot fluid exit °C	26.7	29.4	33.5	35.1	36	36.3
ST-3	Cold fluid exit °C	27	30.5	36.5	38	39.2	39.4
ST-7	Cold fluid inlet °C	26.5	27.9	31.6	32.5	33.7	35.4
ΔT _h	ΔT hot °C	2	5	8.1	7.4	7.1	7.1
ΔT _c	ΔT cold °C	0.5	2.6	4.9	5.5	5.5	4
Q _h	Heat transfer rate for hot fluid W	0.24	0.59	0.96	0.52	0.74	0.94
Q _c	Heat transfer rate for cold fluid W	0.06	0.31	0.58	0.38	0.57	0.53
Q _l	Loss of heat transfer W	0.18	0.28	0.38	0.13	0.17	0.41
E	Effectiveness	23%	40%	49%	55%	59%	50%
Re	Reynold #	2206.79	2206.79	2206.79	1298.11	1947.1	2466.41

Table 4.1.2: Pure copper with mass of fraction (0.375%)

		Pure copper with mass of fraction (0.375%)					
		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30	40	50		50	
T _∞	Room Temperature °C		21.7			21.7	
SC-1 (ṁ _h)	Hot fluid mass flow rate kg/s		1.7/60			1.9/60	
SC-2 (ṁ _c)	Cold fluid mass flow rate kg/s		1.7/60		1.0/60	1.5/60	1.9/60
ST-1	Hot fluid inlet °C	28.3	33	40.4	42.2	42.7	42.9
ST-2	Hot fluid exit °C	26	28.3	32.9	34.9	35.7	36.3
ST-3	Cold fluid exit °C	25.9	28.8	35.1	37.9	38.8	39.5
ST-7	Cold fluid inlet °C	25.3	27.1	31.9	33.5	35.6	36.8
ΔT _h	ΔT hot °C	2.3	4.7	7.5	7.3	7	6.6
ΔT _c	ΔT cold °C	0.6	1.7	3.2	4.4	3.2	2.7
Q _h	Heat transfer rate for hot fluid W	0.27	0.56	0.89	0.51	0.73	0.87
Q _c	Heat transfer rate for cold fluid W	0.07	0.20	0.38	0.31	0.33	0.36
Q _l	Loss of heat transfer W	0.20	0.35	0.51	0.20	0.40	0.52
E	Effectiveness	20%	29%	38%	51%	45%	44%
Re	Reynold #	2185.01	2185.01	2185.01	1285.30	1927.95	2442.07

Table 4.1.3: Pure copper with mass of fraction (0.5%)

		Pure copper with mass of fraction (0.5%)					
		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30	40	50		50	
T _∞	Room Temperature °C		21.7			21.7	
SC-1 (ṁ _h)	Hot fluid mass flow rate kg/s		1.7/60			1.9/60	
SC-2 (ṁ _c)	Cold fluid mass flow rate kg/s		1.7/60		1.0/60	1.5/60	1.9/60
ST-1	Hot fluid inlet °C	26.5	33.3	42.2	43.3	43.7	43.8
ST-2	Hot fluid exit °C	22.7	25.5	30.1	32.2	32.7	33.1
ST-3	Cold fluid exit °C	24.8	28.1	35	37.7	38.3	38.6
ST-7	Cold fluid inlet °C	24.1	25.4	30.2	30.6	32.9	34.9
ΔT _h	ΔT hot °C	3.8	7.8	12.1	11.1	11	10.7
ΔT _c	ΔT cold °C	0.7	2.7	4.8	7.1	5.4	3.7
Q _h	Heat transfer rate for hot fluid W	0.45	0.92	1.43	0.77	1.15	1.41
Q _c	Heat transfer rate for cold fluid W	0.08	0.32	0.57	0.49	0.56	0.49
Q _l	Loss of heat transfer W	0.37	0.60	0.86	0.28	0.58	0.92
E	Effectiveness	29%	34%	40%	56%	50%	42%
Re	Reynold #	2162.85	2162.85	2162.85	1272.26	1908.40	2417.30

Table 4.1.4: Aluminum Oxide with mass of fraction (0.25%)

Aluminum Oxide with mass of fraction (0.25%)		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30 °C	40 °C	50 °C		50 °C	
T _∞	Room Temperature °C		21.7 °C			21.7 °C	
SC-1 (ṁ _h)	Hot fluid mass flow rate kg/s		1.7/60			1.9/60	
SC-2 (ṁ _c)	Cold fluid mass flow rate kg/s		1.7/60		1.0/60	1.5/60	1.9/60
ST-1	Hot fluid inlet °C	26.9	33.9	42.9	45.6	45.1	45.8
ST-2	Hot fluid exit °C	24.6	27.6	32.4	38	36.4	38
ST-3	Cold fluid exit °C	24.1	28.2	35.1	42.5	40.4	42.3
ST-7	Cold fluid inlet °C	23.7	26.3	31.4	39.4	37.3	40.2
ΔT _h	ΔT hot °C	2.3	6.3	10.5	7.6	8.7	7.8
ΔT _c	ΔT cold °C	0.4	1.9	3.7	3.1	3.1	2.1
Q _h	Heat transfer rate for hot fluid W	0.27	0.75	1.24	0.53	0.91	1.03
Q _c	Heat transfer rate for cold fluid W	0.05	0.23	0.44	0.22	0.32	0.28
Q _l	Loss of heat transfer W	0.23	0.52	0.81	0.31	0.59	0.75
E	Effectiveness	13%	25%	32%	50%	40%	37%
Re	Reynold #	2206.79	2206.79	2206.79	1298.11	1947.17	2466.41

Table 4.1.5: Aluminum Oxide with mass of fraction (0.375%)

Aluminum Oxide with mass of fraction (0.375%)		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30 °C	40 °C	50 °C		50 °C	
T _∞	Room Temperature °C		21.7 °C			21.7 °C	
SC-1 (ṁ _h)	Hot fluid mass flow rate kg/s		1.7/60			1.9/60	
SC-2 (ṁ _c)	Cold fluid mass flow rate kg/s		1.7/60		1.0/60	1.5/60	1.9/60
ST-1	Hot fluid inlet °C	30.2	35.9	45.5	45.6	45.5	45.4
ST-2	Hot fluid exit °C	32.5	32.8	38	38.3	38.1	37.6
ST-3	Cold fluid exit °C	35.5	35.5	42.4	42.5	42	41.1
ST-7	Cold fluid inlet °C	37.3	34.7	40.2	39.7	39.6	39.3
ΔT _h	ΔT hot °C	2.3	3.1	7.5	7.3	7.4	7.8
ΔT _c	ΔT cold °C	1.8	0.8	2.2	2.8	2.4	1.8
Q _h	Heat transfer rate for hot fluid W	0.27	0.37	0.89	0.51	0.77	1.03
Q _c	Heat transfer rate for cold fluid W	0.21	0.09	0.26	0.19	0.25	0.24
Q _l	Loss of heat transfer W	0.06	0.27	0.63	0.31	0.52	0.79
E	Effectiveness	84%	67%	42%	47%	41%	30%
Re	Reynold #	2185.01	2185.01	2185.01	1285.30	1927.95	2442.07

Table 4.1.6: Aluminum Oxide with mass of fraction (0.5%)

		Run-1	Run-2	Run-3	Run-4	Run-5	Run-6
T	Temperature °C	30 °C	40 °C	50 °C		50 °C	
T _∞	Room Temperature °C		21.7 °C			21.7 °C	
SC-1 (ṁh)	Hot fluid mass flow rate kg/s		1.7/60 kg/s			1.9/60 kg/s	
SC-2 (ṁc)	Cold fluid mass flow rate kg/s		1.7/60 kg/s		1.0/60 kg/s	1.5/60 kg/s	1.9/60 kg/s
ST-1	Hot fluid inlet °C	27.9	34.3	42.5	43.1	43.6	43.8
ST-2	Hot fluid exit °C	24.3	26.3	30.2	31.2	31.8	32.4
ST-3	Cold fluid exit °C	24	27.6	33.6	35.5	36	36.5
ST-7	Cold fluid inlet °C	22.6	24.7	28.9	29.6	31.3	32.8
ΔTh	ΔT hot °C	3.6	8	12.3	11.9	11.8	11.4
ΔTc	ΔT cold °C	1.4	2.9	4.7	5.9	4.7	3.7
Qh	Heat transfer rate for hot fluid W	0.43	0.95	1.45	0.83	1.23	1.51
Qc	Heat transfer rate for cold fluid W	0.17	0.34	0.56	0.41	0.49	0.49
Ql	Loss of heat transfer W	0.26	0.60	0.90	0.42	0.74	1.02
E	Effectiveness	26%	30%	35%	44%	38%	34%
Re	Reynold #	2162.85	2162.85	2162.85	1272.26	1908.40	2417.30

4.2 Graphs

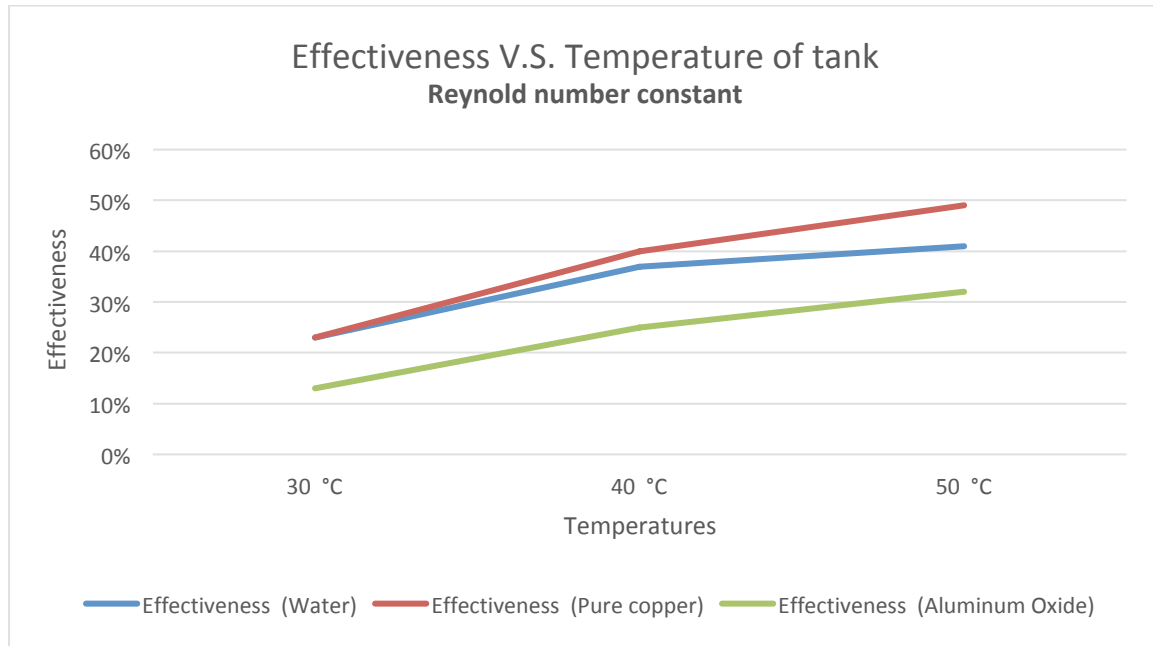


Figure 4.2.1: Effectiveness V.S. Temperature of tank (Reynold number constant) with mass of fraction (0.25%).

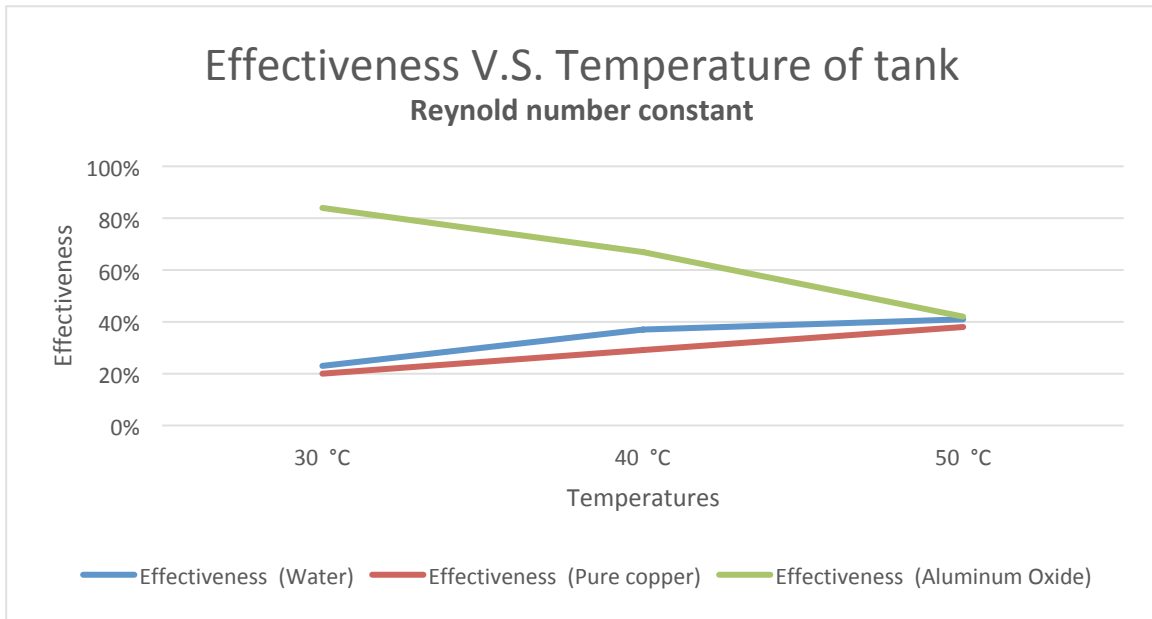


Figure 4.2.2: Effectiveness V.S. Temperature of tank (Reynold number constant) with mass of fraction (0.375%).

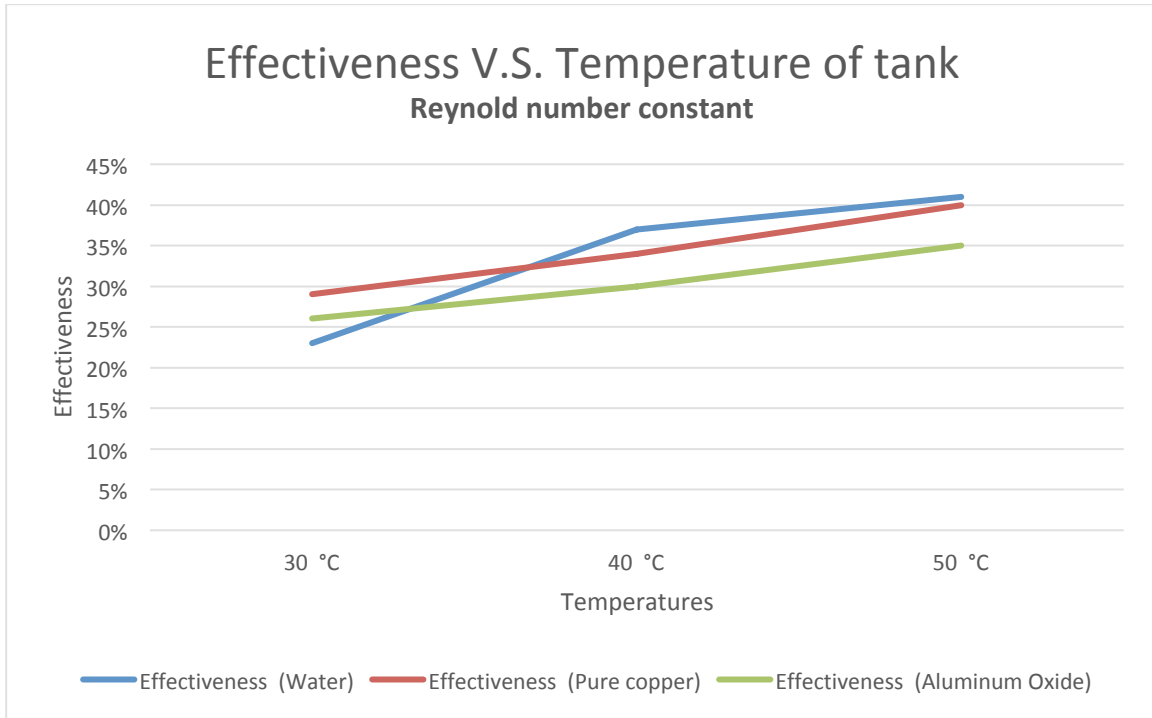


Figure 4.2.3: Effectiveness V.S. Temperature of tank (Reynold number constant) with mass of fraction (0.5%).

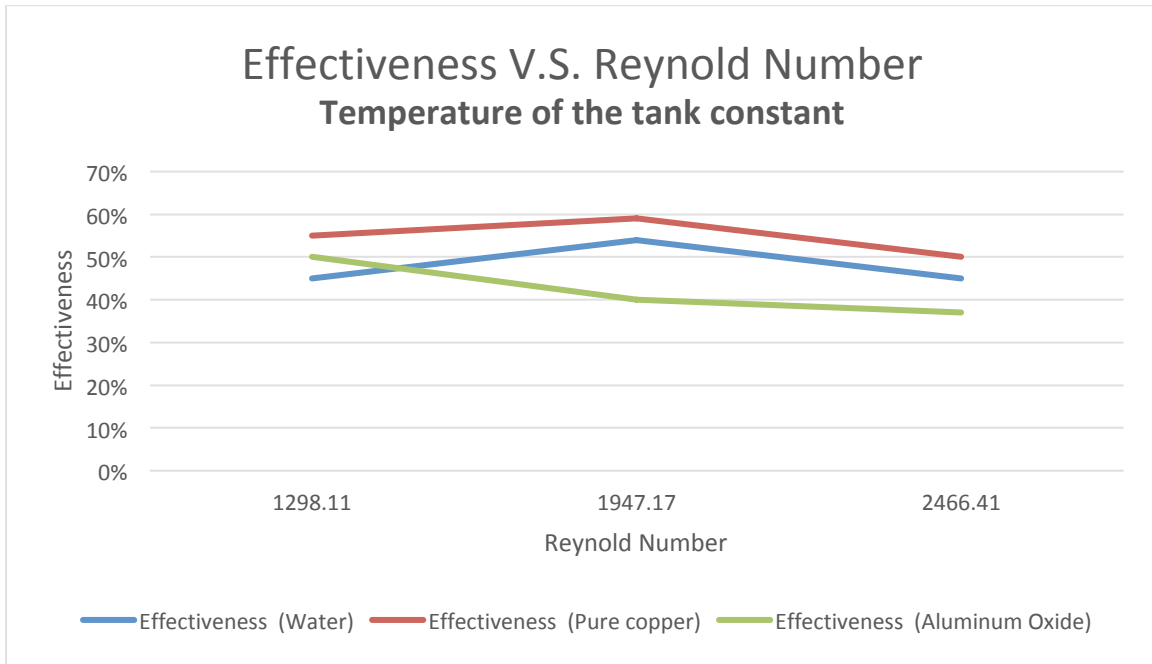


Figure 4.2.4: Effectiveness V.S Reynold number constant (Temperature of tank) with mass of fraction (0.25%).

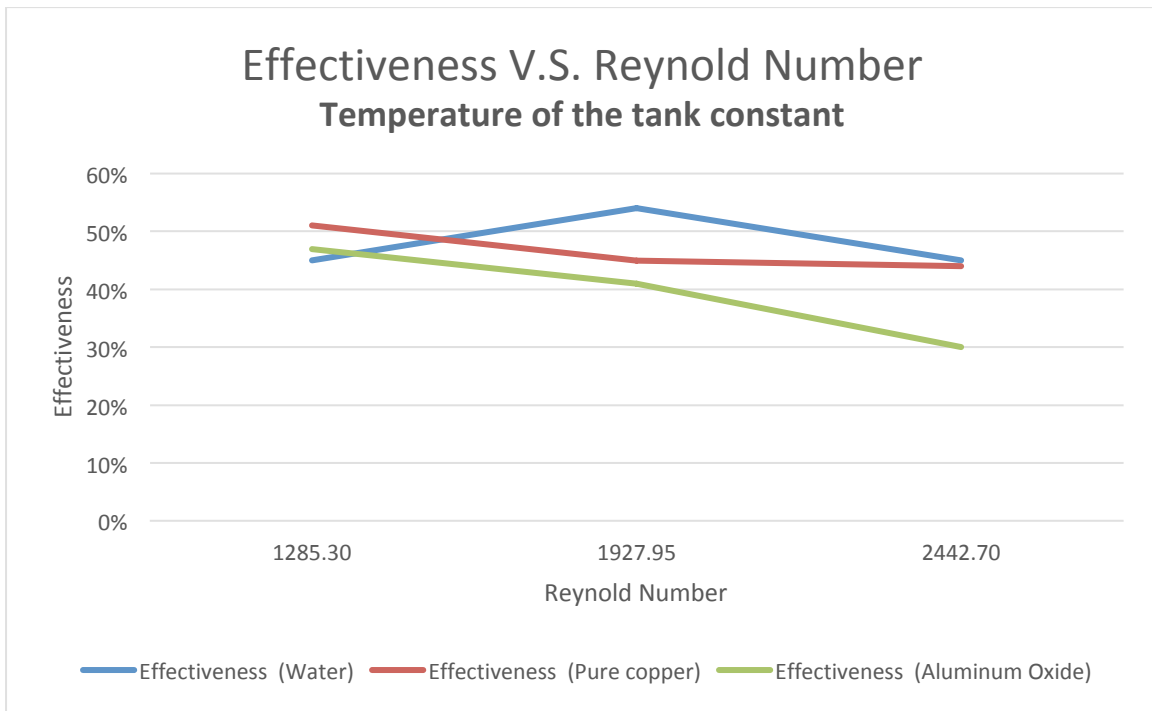


Figure 4.2.5: Effectiveness V.S Reynold number constant (Temperature of tank) with mass of fraction (0.375%).

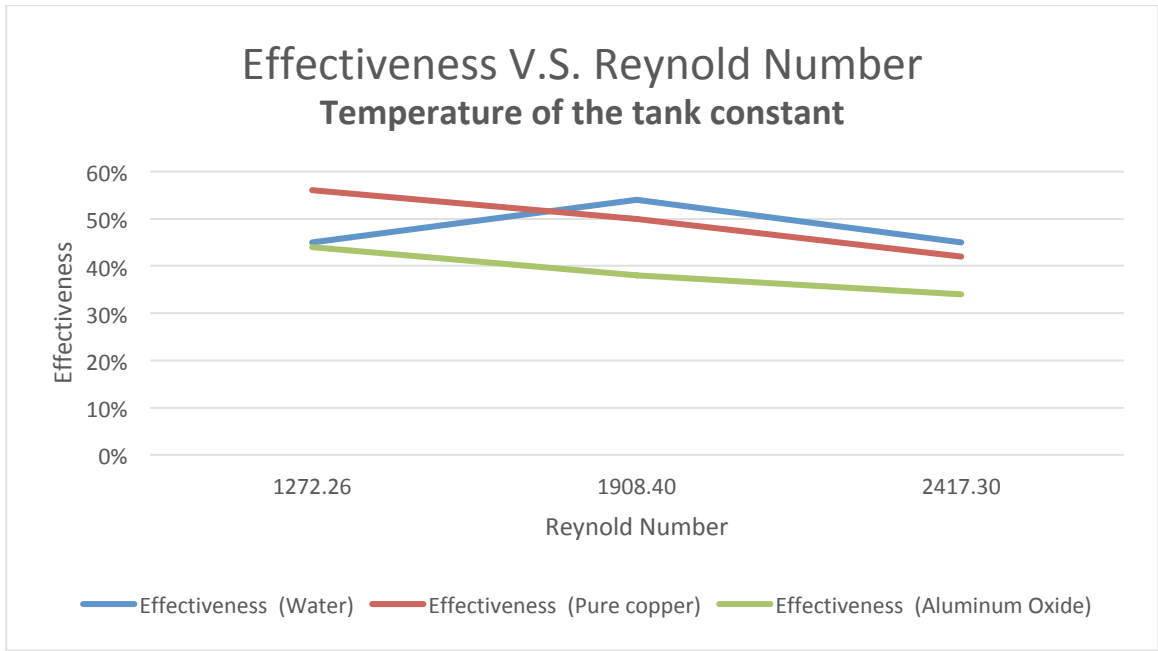


Figure 4.2.6: Effectiveness V.S Reynold number constant (Temperature of tank) with mass of fraction (0.5%).

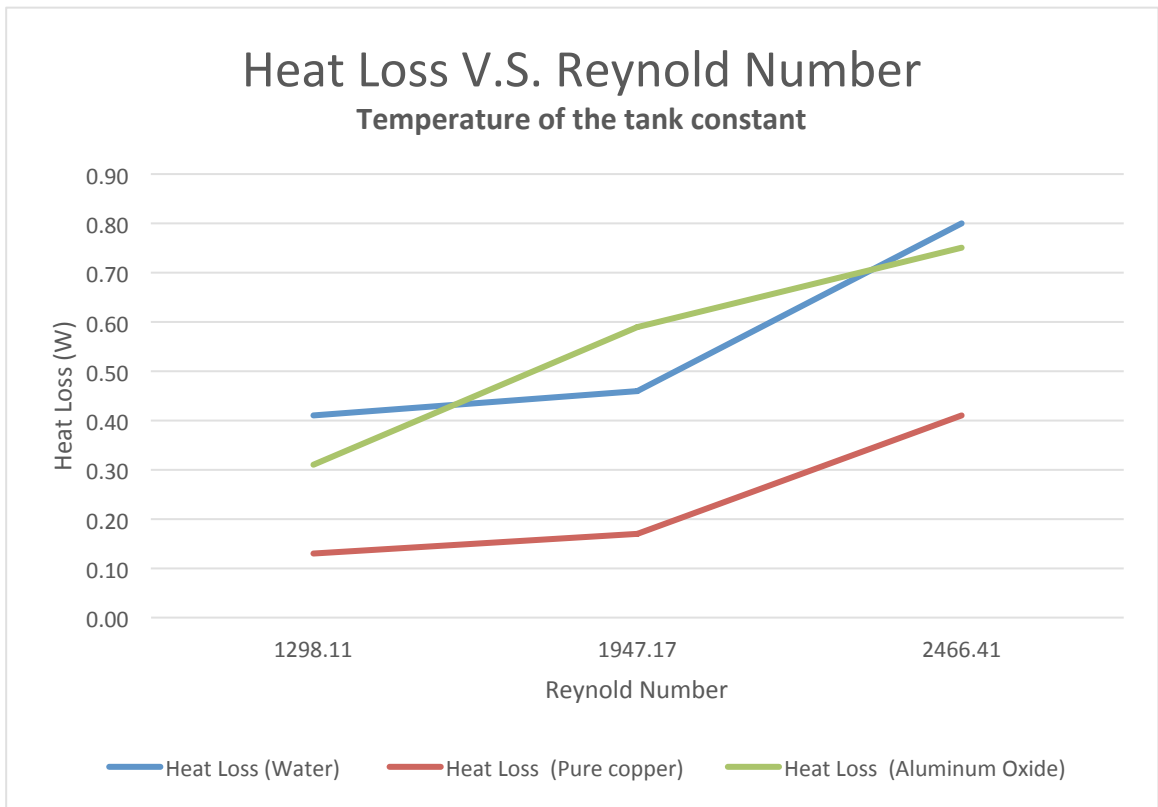


Figure 4.2.7: Heat Loss V.S. Reynold Number (Temperature of the tank constant) with mass of fraction (0.25%).

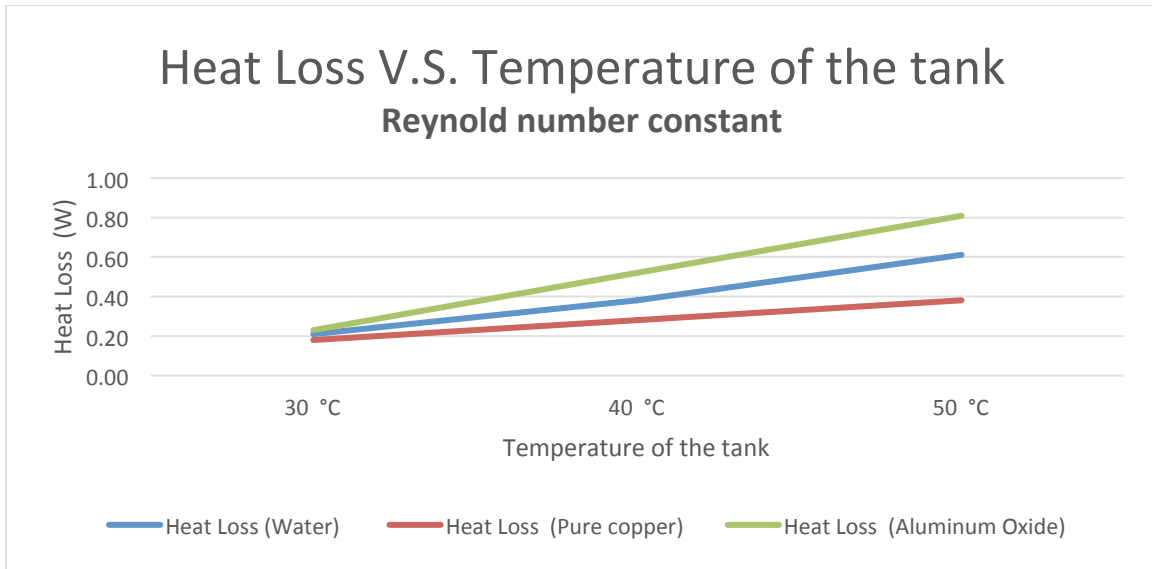


Figure 4.2.8: Heat Loss V.S. Temperature of the tank (Reynold Number constant) with mass of fraction (0.25%).

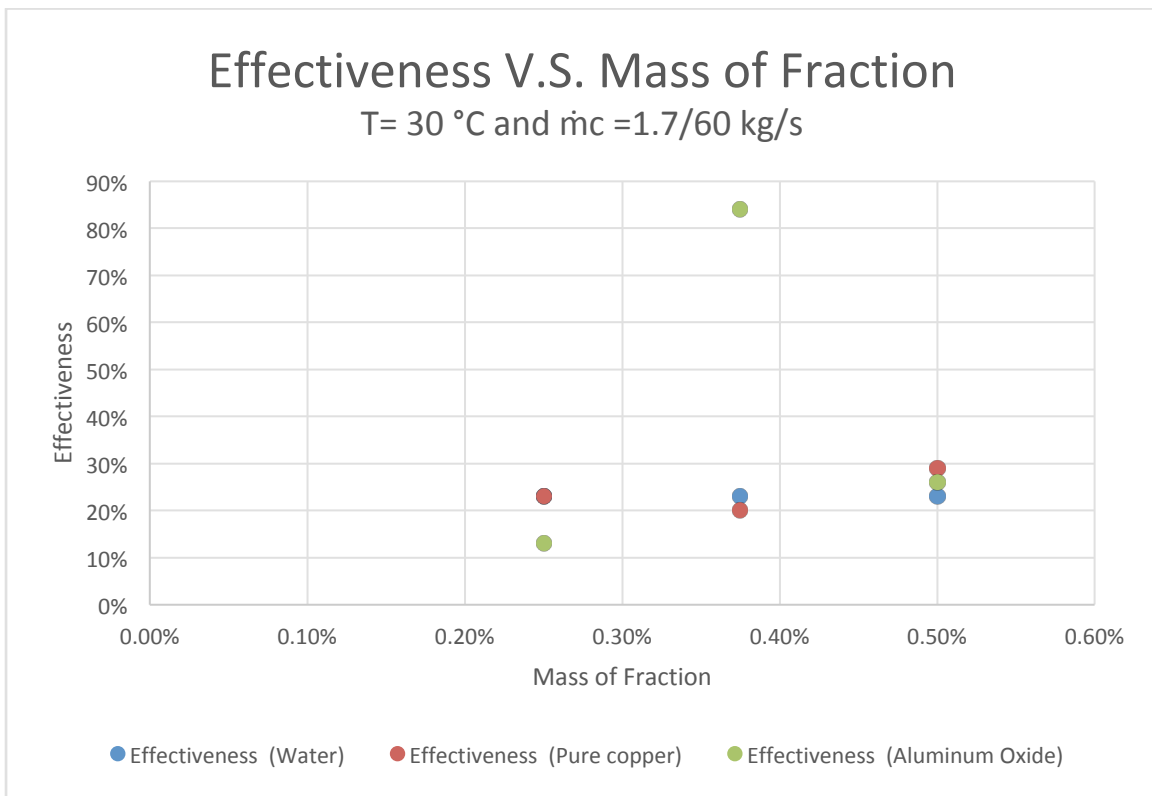


Figure 4.2.9: Effectiveness V.S. mass of Fraction (T= 30 °C and $\dot{m}c = 1.7/60$ kg/s).

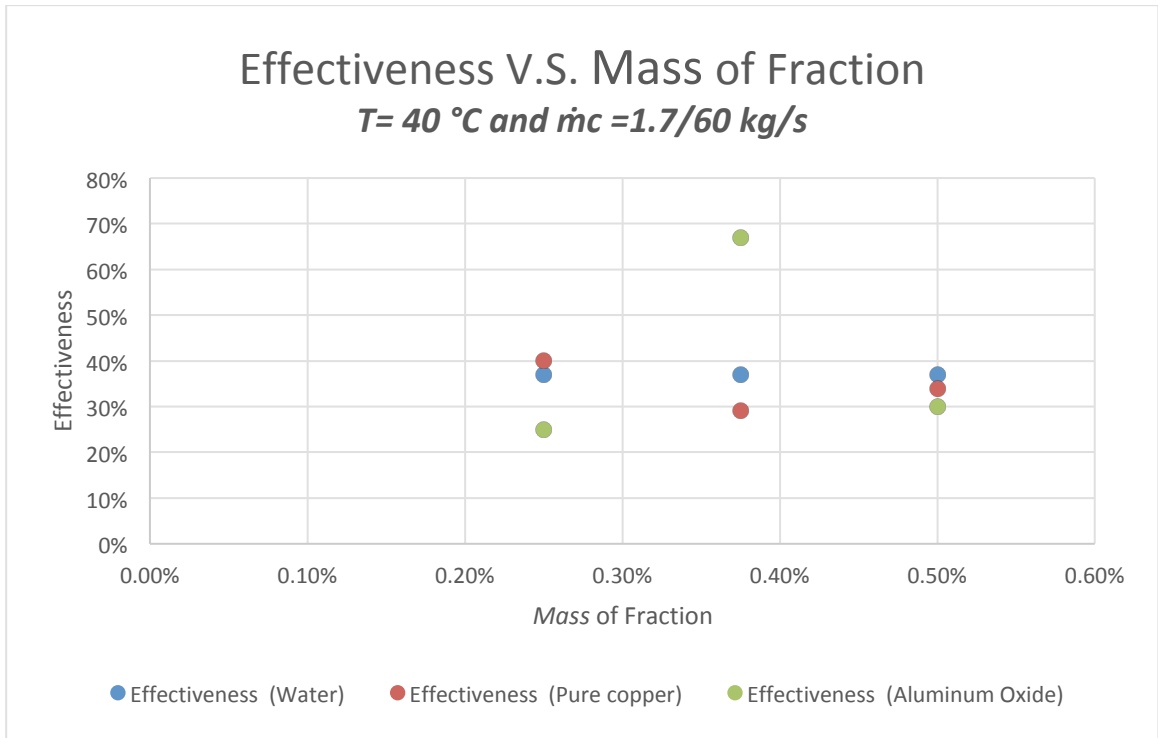


Figure 4.2.10: Effectiveness V.S. mass of Fraction ($T = 40\text{ }^{\circ}\text{C}$ and $\dot{m}c = 1.7/60\text{ kg/s}$).

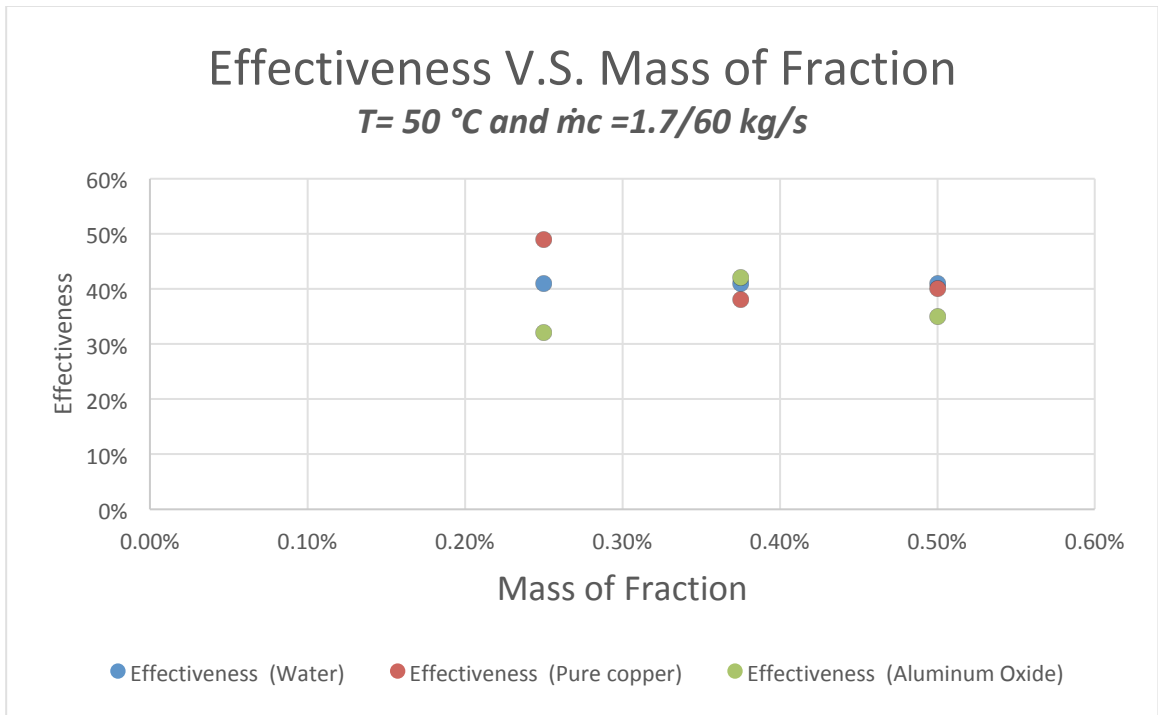


Figure 4.2.11: Effectiveness V.S. mass of Fraction ($T = 50\text{ }^{\circ}\text{C}$ and $\dot{m}c = 1.7/60\text{ kg/s}$).

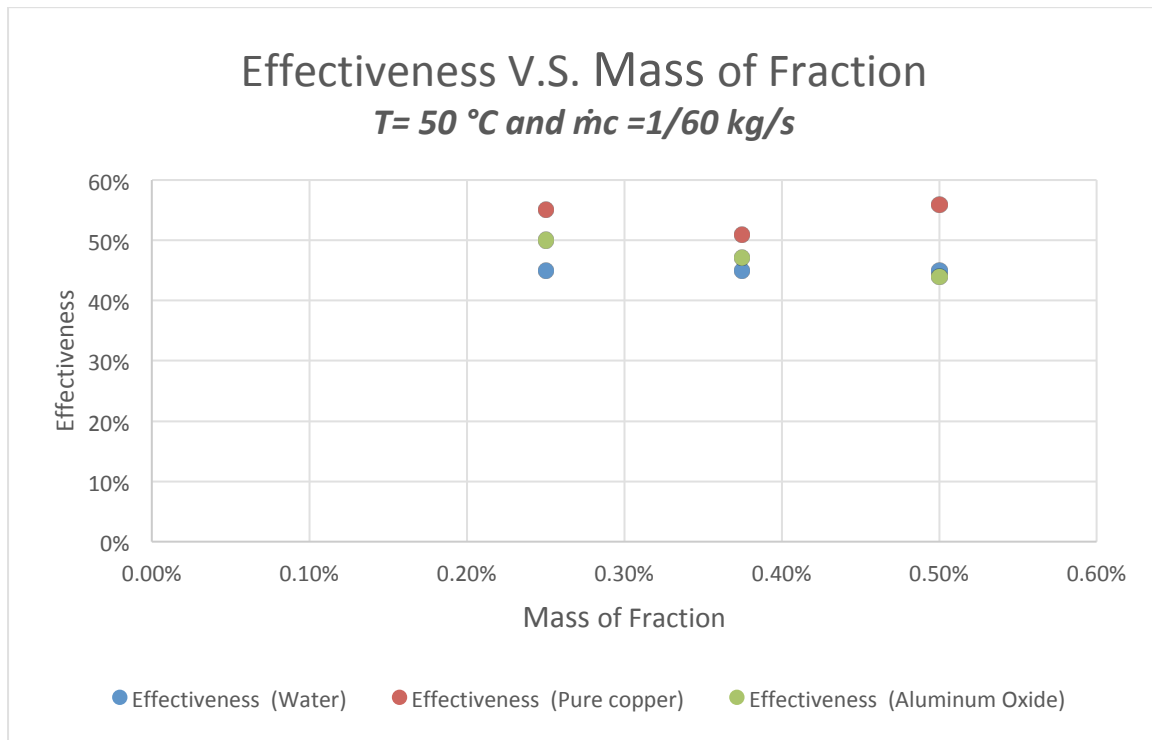


Figure 4.2.12: Effectiveness V.S. mass of Fraction ($T = 50\text{ }^\circ\text{C}$ and $\dot{m}c = 1/60\text{ kg/s}$).

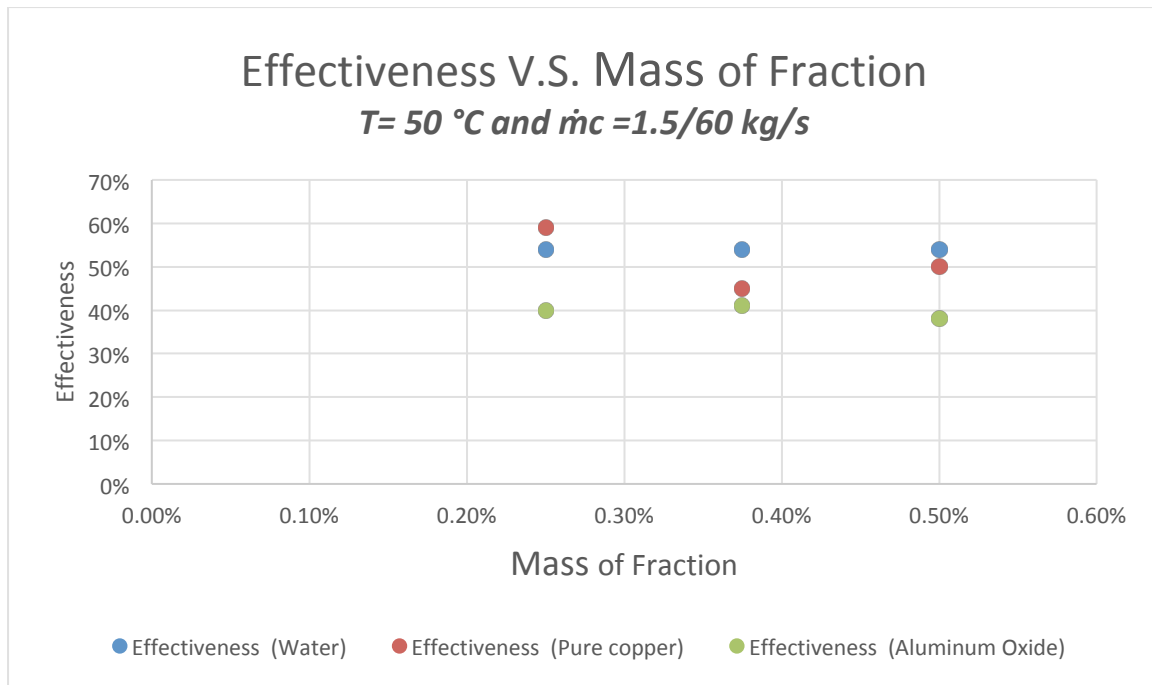


Figure 4.2.13: Effectiveness V.S. mass of Fraction ($T = 50\text{ }^\circ\text{C}$ and $\dot{m}c = 1.5/60\text{ kg/s}$).

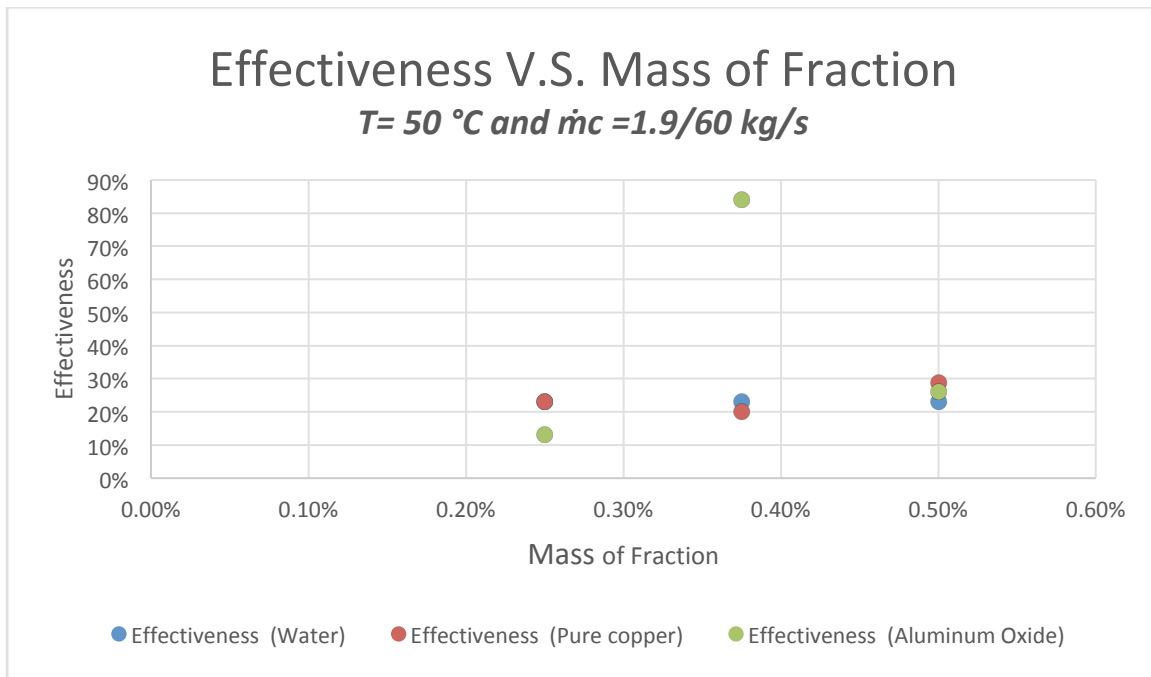


Figure 4.2.14: Effectiveness V.S. mass of Fraction (T= 50 °C and $\dot{m}_c = 1.9/60$ kg/s).

Chapter 5: Project Management

5.1 Project Plan

The project was planned with including tasks and subtasks distributed to the group members. All group members contributed to performing these tasks and subtasks as shown in Table 5.2: Gantt chart below, tasks are planned to be performed with consideration of due date. This management was successful to finish the project on time successfully.

5.2 Contribution of Team Member

All the members were effective. We shared ideas, exchange ideas and opinions. All of the team members have participated in the project in accordance with the Gantt chart and the agreed working plan. Below is the table showing the main tasks that have been done with the timing of each task.

Table 5.2: List of tasks and the team member assigned with time duration of each task.

	Tasks	Subtasks	Responsible	Due date of the Tasks	Duration (Days)	Start Date	Finished Date	Status			
Initiation	Kick off meeting	Identifying the project, Group formation and Gantt chart	All Team	Week 2 (10 of January)	4	07/01/19	11/01/19	Completed			
Introduction (Chapter 1 & Chapter 2)	Project allocation + introduction	Project Definition,	Waleed	Week 5 (7 of February)	5	12/01/19	17/01/19	Completed			
		Project Objectives	Ali		5						
		Project Specifications	Muntathar		5						
		Applications	Abdulhadi		5						
	Literature Review	Project background	All Team		14	18/01/19	01/02/19	Completed			
		Previous Work									
Comparative Study											
System Design (Chapter 3)	Design	Design Constraints and Design Methodology	Abdulhadi & Waleed	Week 7 (21 of February)	6	02/02/19	08/02/19	Completed			
	Equipment and material selection (3.4)	selected the appropriate items	Ali & Muntathar		4	09/02/19	13/02/19	Completed			
	Theory and Theoretical Calculations	main calculations required detailed calculations to your design.	Ali & Muntathar		5	14/02/19	19/02/19	Completed			
	Prototype assemble	System integration, describe , procedures and Implementation	Abdulhadi & Waleed		5	14/02/19	19/02/19	Completed			
System Testing and Analysis (Chapter 4)	Testing and analyses	Experimental Setup, Sensors and data acquisition system	All Team	7	20/02/19	27/02/19	Completed				
		Results, Analysis and Discussion									
Project Management and Project Analysis (Chapter 5)	Project Management	Project Plan	All Team	Week 13 (4 of April)	12	28/02/19	12/03/19	Completed			
		Contribution of Team Members									
		Project Execution Monitoring									
		Challenges and Decision Making									
		Project Bill of Materials and Budget							Ali	08/02/19	10/04/19
	Project Analysis	Life-long Learning	Abdulhadi		14	13/03/19	27/03/19	Completed			
Impact of Engineering Solutions		Waleed									
Contemporary Issues Addressed		Muntathar									
Report submission	Final Report	Writing all chapters	Ali	Week 14 (14 of April)	3	28/03/19	31/03/19	Completed			
	Presentation preparation	Making Slides	Waleed					Completed			
	Presentation practice	A dry run presentation	All Team					4	31/03/19	04/04/19	Completed
	Booklet	Print the report	Muntathar					3	05/04/19	08/04/19	Completed
	Banner	Follow rubric	Abdulhadi								Completed
	Brochure	Follow rubric	Abdulhadi and Ai								Completed
	Final Presentation	Present our presentation	All Team					1	09/04/19	10/04/19	In-Progress
Monthly progress report	1st progress report	Waleed and Muntathar	3	Monthly	06/01/19	31/01/19	Completed				
	2nd progress report				01/02/19	28/02/19	Completed				

5.3 Project Execution Monitoring

On the weekly meeting and discussion of the updated progress, the team reviews the participation of each member and discusses the previous work and planning for next part. All meetings were helpful for each member because every member tried to exchange his own idea with others. When we face any problem, we try our best solution to ask our advisor about it. The advisor was successful to help us and find the solution by ourselves. Below is the table for our meetings:

Table 5.3: Project Execution Monitoring Activities.

Activity	Time
Member's meeting	Weekly, and anytime if needed.
Advisor meeting	One times every two weeks, and anytime if needed.
Testing meeting	2 times at a pre-testing phase 5 times at final testing phase

5.4 Challenges and Decision Making

The main challenge we got in this project while doing experiments. It was very tough to perform an experiment because of the class schedule and availability of all group members.

Some of the materials ordering were from the global market as an online order since it is not available on the local market. We face difficulties for providing our needed material from the global market, since we needed to have unordinary material. For example, nanoparticles size and specification. Assembly of the setup was also one of the tough tasks, which we did with the help of coordination between our team members. Writing and documenting the progress of the project was also challenging because of a very limited time.

5.5 Project Bill of Material and Budget

The below table shows the materials we used for our design and the cost of each items:

Table 5.5: List of tasks and the team member assigned with time duration of each task.

Material	Cost
Pure Copper Powder Nano Particle	3082.76 SR
Aluminum Oxide Powder Nano Particle	1251.4 SR
Joining Fittings and Piping	430 SR
Custom Payment	445 SR
Brochures, Poster and Wire Bound	1810 SR
Total	7019.16 SR

Chapter 6: Project Analysis

6.1 Life Long Learning

This project experience we got as a team helped us to compute our skills and knowledge gained in our undergrad study. We got to know about teamwork to solve any difficulty we might face. What makes our implementation of the competencies special is that we had a project required a lot of teamwork, leadership, and technical communication skills. Time and cost management also plays a significant factor as well in this project because it required necessary equipment with high quality and ensure its functionality and efficiency within the cost. With all that, we as the team successfully had done this iconic project within time and cost limitations.

6.1.1 Improve our Skills in Some Software Tools

The technical skills are one thing of each project and the other thing is software skills. We applied and used the software tools used in this project like 3- Dimensional Computer Aided Design (3D CAD) which we used for designing heat exchanger model and Microsoft word, Excel for preparing project documents and reports. These software tools were played very important role in this project and we have learned many things, which gave us very good experience. All technical skills used in this project, which provided the best result because of the well knowledge of software tools and regularly using in professional way.

6.1.2 Time Management Skill

Effective planning of time was one of the most important parts of this project. In this project we learnt about the time management skills, which are required to give the best result to your efforts. We also include extra time because most of the time things will not go as planned. We also developed the ability to manage time effectively and it was very helpful for all of us. After all the planning and estimation for each task, we made a project schedule graph, which includes all tasks and their duration. We made the Gantt chart, which was really a staple of project management that helped in schedule activities and assign resources.

6.1.3 Problem Solving

The problem-Solving skills are very important to solve industrial challenges. It makes person capable to deal with issues and problems with an easy approach. This problem solving skill we got to learn in this project, which helped us to gain knowledge and technical ideas while we faced the problems in our project. It is a simple, systematic way to approach a problem with clearly defined steps. While doing project we faced many problems that we solved eventually.

6.2 Impact of Engineering Solution

When it comes to the impacts from our project, we have achieved the great impact from this project on the society, environment, and economy.

6.2.1 Society

The society is the most important thing for every project. If a project has been succeeded to satisfy the society then that project is called as successful project and also which is useful for society.

This project has lots of social impacts, as we know that whole world is facing energy crisis so increasing the heat exchanger efficiency slightly by any means can affect the society positively.

6.2.2 Environmental

The environment is the main assessment for developing every project, which is basically concerned with the identification and assessment of the environmental effects of development projects, plans, programs and policies.

The global increasing demand for heat transfer between two mediums required the efficient heat transfer methods to save energy and environment. Energy is produced by burning fossil fuels, which causes environmental pollution and global warming. So, by efficient use of heat energy we can save environment.

6.3 Conclusion

The result is shown improvement in efficiency when using nanoparticles as a heat transfer medium since nanoparticles possess more advantageous to the conventional heat transfer resulting in transferring heat more efficiently. The results of nanofluids of Aluminum oxide and pure copper are distributed into three categories in accordance with the volume of the fraction, as followed: 0.25%, 0.375%, and 0.5%. The effectiveness is one of the main improvements that happened while using nanoparticles. The efficiency increases with increasing the inlet temperature of the hot fluid tank, and the inverse relationship between the mass flow rate and the efficiency makes the efficiency decreases due to increasing of the mass flow rate. On the other hand, the heat losses are decreased in the pure copper and in the Aluminum oxide nanoparticles. Finally, our experiment in how to improve the effectiveness in the shell and tube heat exchanger has been succeeded by using these types of nanoparticles.

6.4 Future Recommendation

As a team, we come up with some recommendations that when we are looking for the more trusted result we need to use more mass of fraction that exceeds 1% which means that will cost a lot of money. Moreover, for the mass flow rate sensor, we should have a sensor that can read both the water and nanoparticles fluid.

References

1. Choi, S. U. S., Singer, D. A., & Wang, H. P. (1995). Developments and applications of non-Newtonian flows. *ASME FED*, 66, 99-105.
2. Xuan, Y., & Li, Q. (2003). Investigation on convective heat transfer and flow features of nanofluids. *Journal of Heat transfer*, 125(1), 151-155.
3. Wen, D., & Ding, Y. (2004). Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions. *International journal of heat and mass transfer*, 47(24), 5181-5188.
4. Xuan, Y., & Roetzel, W. (2000). Conceptions for heat transfer correlation of nanofluids. *International Journal of heat and Mass transfer*, 43(19), 3701-3707.
5. Pak, B. C., & Cho, Y. I. (1998). Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. *Experimental Heat Transfer an International Journal*, 11(2), 151-170.
6. Li, Q., & Xuan, Y. (2002). Convective heat transfer and flow characteristics of Cu-water nanofluid. *Science in China Series E: Technolical Science*, 45(4), 408-416.
7. Lotfi, R., Saboohi, Y., & Rashidi, A. M. (2010). Numerical study of forced convective heat transfer of nanofluids: comparison of different approaches. *International Communications in Heat and Mass Transfer*, 37(1), 74-78.
8. Aghayari, R., Madah, H., Keyvani, B., Moghadassi, A., & Ashori, F. (2014). The Effect of Nanoparticles on Thermal Efficiency of Double Tube Heat Exchangers in Turbulent Flow. *ISRN Mechanical Engineering*, 2014.
9. Hassani, S. S., Amrollahi, A., Rashidi, A., Soleymani, M., & Rayatdoost, S. (2016). The effect of nanoparticles on the heat transfer properties of drilling fluids. *Journal of Petroleum Science and Engineering*, 146, 183-190.
10. Mahrooghi, A., & Moghiman, M. (2015). Effect of nanoparticles on heat transfer in heat exchangers. *Ciência e Natura*, 37, 199-206.
11. Sessaiah, N., & Reddy, C. S. Influence of nanoparticles on the effectiveness of heat exchanger and associated pressure drop.